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AUTHOR	Westbrook, Susan L.; Rogers, Laura N.
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ABSTRACT

A study was designed to test the hypothesis that a descriptive-type learning cycle was insufficient to stimulate students to reason at a reflective level or to develop an understanding of, and facility with, the processes of scientific investigation. In order to test the hypothesis, four classes of ninth-grade physical science students (n=100) participated in a series of three learning cycles on simple machines. All students engaged in descriptive-type exploration activities followed by invention discussions. The control group conducted prescribed experiments, one experimental group designed experiments to answer a teacher-provided question, and another experimental group generated and tested its own hypothesis. The effects of the treatments were assessed through a pretest-posttest design using Lawson's Seven Logic Tasks, The Test of Integrated Process Skills, and Lawson's revised Classroom Test of Scientific Reasoning (CTSR). All significant gains were made by the two experimental groups. Females in all three groups scored significantly lower than males on the CTSR posttest, although the gender effect was neutralized when students were categorized according to Lawson's criteria for concrete, transitional, and formal. (31 references, 3 tables) (KR)

An Analysis of the Relationship Between Student-Invented Hypotheses and the Development of Reflective Thinking Strategies

Susan L. Westbrook
Norman Public Schools
Norman, OK 73069

Laura N. Rogers
University of Oklahoma
Norman, OK 73019

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Abstract

The present study was designed to test the hypothesis that a descriptive-type learning cycle (see Lawson, Abraham, & Renner, 1989) was insufficient to stimulate students to reason at a reflective level or to develop an understanding of, and facility with, the processes of scientific investigation. A learning cycle format designed to allow students to experience a concept at a descriptive level and to explore that concept through the generation and testing of hypotheses should (a) positively impact student understanding of the reasoning and processes inherent in science and (b) enhance intellectual development. In order to test the hypothesis, students in a ninth grade physical science course participated in a series of three learning cycles on simple machines. All students in the study engaged in descriptive-type exploration activities followed by invention discussions. The expansion phase of each learning cycle was then varied from being strictly descriptive (control group) to provide students in one experimental group (HT) opportunity to generate and test hypotheses about phenomena related to the main concept of the investigation. A second experimental group (QD) designed experiments to answer a question posed by the teacher. The effects of the treatments were assessed through a pretest-posttest design using Lawson's Seven Logic Tasks, The Test of Integrated Process Skills (I), and Lawson's revised Classroom Test of Scientific Reasoning. No significant gains were found among the three groups on any of the three test instruments. The students within the HT group did exhibit a significant gain on the TIPS test ($p=.0046$). Students in both the HT and QD groups exhibited a significant shift in one of the seven items on Lawson's Logic Tasks. These data suggest that changes in the type of laboratory activities students experience in the learning cycle may influence the development of logical thinking and enhance the use of process skills.

An Analysis of the Relationship Between Student-Invented Hypotheses and the Development of Reflective Thinking Strategies

Introduction

The learning cycle has been implemented and researched in science classrooms for almost thirty years. Robert Karplus (Karplus and Thier, 1967), influenced by Piaget's mental functioning model, initiated the development of an inquiry-based curricular model which consisted of three phases (exploration, invention, and discovery). That pedagogy has since become known as the learning cycle. Although the names of the phases have undergone modification, the premise that concrete experience and social interaction are necessary for learning has continued to drive the development of learning cycle curricula.

The initial studies involving the learning cycle were conducted in elementary school science classrooms. The data from those projects with the Science Curriculum Improvement Study indicated that the learning cycle format could accelerate the acquisition of conservation reasoning (Renner, et al., 1973). Later investigations involving adolescents in learning cycle science courses suggested that the use of this theory-driven instructional strategy in science classrooms increased student understanding of science concepts and improved student reasoning abilities (Saunders and Shepardson, 1987; Purser and Renner, 1983; and Schneider and Renner, 1980). Recent data collected in learning cycle-related research do not convincingly support the contention that learning cycle curricula have a significant positive effect on student comprehension, use of science process skills, or reasoning abilities. Renner, Abraham, and Birnie

(1985) reported that students in a learning cycle high school physics class liked the laboratory format, but no statistical differences in concept understanding were found among students experiencing different forms of the phases of the learning cycle. Those form changes included traditional expository presentation of the information. In a related study involving high school students in a learning cycle chemistry class, deviations in the sequence of the phases of the learning cycle did not appear to effect student comprehension (Abraham, Renner, and Birnie, 1986). Marek and Westbrook (1990, unpublished data) indicated that students in grades seven through twelve did not show significant gains in formal reasoning ability or in the ability to use science process skills after participating in a year-long learning cycle program. Westbrook, Bryant, and Marek (1989) reported that students in a tenth-grade learning cycle biology course were outscored by students in a traditional exposition class in every content area of a nationally published standardized test. The test included several items designed to determine the students' abilities to analyze and interpret data and test scientific hypotheses. The students in the exposition course, who had no laboratory experience other than animal dissections, achieved higher scores than the learning cycle students on the process-oriented test items. The students in the learning cycle classes did exhibit better understanding of the concept of photosynthesis and related terminology.

Why do the recent data gathered about students involved in learning cycle courses not parallel the predicted gains in scientific reasoning, acquisition of process skills, and

intellectual development? It could be argued that student abilities have changed since the time the original data were obtained and published. This explanation could be supported by the low scores on international mathematics, language arts, and science comprehension tests currently reported for American students (Appleby, Langer, and Mullis, 1986; IAAEEA, 1987; IAAEEA, 1988). However, data related to the reasoning abilities of students in recent studies (Westbrook and Marek, 1990) are almost identical to those collected from students tested twenty years ago (Renner, et al., 1973). In addition, Kyle, et al. (1988) reported that elementary school students who participated in SCIIS programs exhibited better attitudes toward science and scientists than students in traditional elementary school science programs. The SCIIS students also outscored the textbook-taught students on eight questions related to scientific content.

There is a more plausible, and more testable, explanation for the recent data generated in research projects involving learning cycle curricula. The design and implementation of the learning cycle curricula written may not maximize the inherent effectiveness of the pedagogy with respect to scientific reasoning, intellectual development and concept acquisition. A dissonance may exist between the theoretical expectations of the model and the written curricula. Three different learning cycle types have already been identified and described by Lawson, Abraham, and Renner (1989): descriptive, empirical-abductive, and hypothetico-deductive. Each type of learning cycle is characterized by the particular level of reasoning required of the participating students. Descriptive learning cycles allow the

students to describe patterns within a particular context. The students are required to utilize basic reasoning patterns (i.e. seriation, classification, and conservation). The empirical-abductive learning cycle provides students with an opportunity to describe patterns and also encourages the generation of possible causes for those patterns. The students must utilize descriptive reasoning patterns combined with higher order reasoning skills. The hypothetico-deductive learning cycle challenges the student to develop alternative hypotheses to explain an event. The student then designs experiments to test those hypotheses. In the hypothetico-deductive learning cycle the student is forced to implement higher order reasoning skills such as controlling variables, correlational reasoning, and hypothetico-deductive reasoning.

The learning cycle curricula used in the studies reviewed previously were of the descriptive type. The students were asked to describe patterns in the data, describe basic relationships among the variables, and answer questions designed to help the student to invent the concept. If the curriculum provided a detailed script for the investigation, then the students were not compelled to reason beyond describing patterns in the data. If the students did not have to involve themselves in hypothesis testing, the separation of variables, or other processes related to scientific investigation, then it seems unlikely that the students would show gains on tests that measure the ability to use those processes.

Lawson alluded to this relationship between the nature of the curriculum and the quality of student reasoning. In a recent

report Lawson (1990) labeled students whose reasoning was dependent upon specific situations and who exhibited biconditional logic patterns as intuitive thinkers. In contrast, the reflective thinker, according to Lawson, was able to acknowledge the existence of, and look for, alternative explanations before drawing inferences from a set of data. Thus, Lawson viewed adolescent intellectual development as a matter of the acquisition of a disposition to consider alternative hypotheses as well as the ability to utilize the mental schemes (control of variables, correlational and probabilistic reasoning) necessary to test those hypotheses. Lawson concluded that the educational implications of this view of advanced reasoning was a curriculum that encouraged students to consider and test alternative hypotheses. A curriculum of that scope would allegedly provoke the acquisition of reflective reasoning patterns as well as enhance general intellectual development.

Purpose of the Study

The present study was designed to test the hypothesis that the descriptive-type learning cycle is insufficient to stimulate students to reason at a reflective level or to develop an understanding of, and facility with, the processes of scientific investigation. A learning cycle format designed to allow students to experience a concept at a descriptive level and to further explore that concept through the generation of alternative hypotheses should (a) positively impact student understanding of the reasoning and processes inherent in science and (b) enhance intellectual development.

Method

The subjects in the study were four classes (n=100) of ninth grade students enrolled in physical science in a midwestern city. The mean age of the sample was 15.3 years. A learning cycle program developed by Norman Public Schools in association with the University of Oklahoma Science Education Center served as the course curriculum. Prior to the investigations used in the research project, the students had studied electric circuits and current, electromagnetism, and light. The concepts were always presented through a descriptive-type exploration in which the students gathered data specified in the investigation and organized the data in prepared data tables. The data were then analyzed in a class discussion led by the teacher. The format of the expansion phases had been varied to give the students the opportunity to design and conduct experiments.

A unit on simple machines was selected for the research project. Three learning cycle investigations were used: levers, balance on a lever, and pulleys and inclined planes. Each of the four classes was assigned to participate in one of three types of expansion activities. The teacher-researcher, a female in her mid-thirties, taught the four classes of students involved in the study. The researcher determined that a short term influence would be of less effect than a longer exposure, thus, the format of the treatment of the three groups was not altered or varied through the three investigations.

A description of the treatment each group received follows.

1. The *Control Group* (CT) participated in the learning cycles written in the physical science curriculum. The students

followed the instructions given in the student sheets, organized the data on prepared data tables, and then repeated these processes in expansion phase activities. Students were given no opportunity to design experiments or generate and test hypotheses.

2. The *Question-Design Grcup* (QD) followed the written guidelines in the program for the exploration phase of each investigation. At the onset of the expansion phase the teacher gave the students a question concerning an idea related to the main concept of the investigation. The students were instructed to design experiments to answer the question. After the expansion activities had been completed, the students shared and discussed the nature of the investigations, the results, and the implications. Each student was required to write a short report about the investigation that included the materials, methods, data tables, graphs, and conclusions

3. The *Hypothesis Testing Group* (HT) followed the guidelines in the program for the exploration phase of each investigation. These students then participated in expansion activities which began with a class discussion to generate an hypothesis that the class would test. The students designed their own experiments to provide information related to the hypothesis. The students shared their findings and discussed whether their data supported or refuted the hypothesis. Each student was required to write a report similar to that prepared by the students in the QD group.

The effect of the experimental treatments was tested using three instruments. A pretest-posttest design was used. The instruments included:

1. *Lawson's Classroom Test of Scientific Reasoning: Revised Pencil-Paper Edition* (Lawson, 1987a) was used to measure the student's level of intellectual development. The test consisted of ten items designed to assess conservation of weight and volume, proportional reasoning, separation of variables, propositional logic, combinatorial reasoning, and correlations. Each item consisted of a problem requiring a solution and a written explanation. The student was given 1 point for each item for which a correct response was given for both the initial problem and the written explanation. According to Lawson, the students with scores of 0 to 3 were considered concrete operational. Students scoring between 4 and 6 points were categorized as transitional. Students were grouped as formal operational if they scored from 7 to 10 points on the test.

2. *Lawson's Seven Logic Tasks* (Lawson, 1990) were used to determine whether the student utilized conditional or biconditional logic patterns. The test consisted of seven tasks each which required the student to evaluate four items and respond as to whether a conclusion could or could not be made based on the antecedent. The student was given a score of 1 if the biconditional form was used for one to three of the questions asked in the task. A score of 2 was given if the conditional form was used for all four task questions.

3 *The Test of Integrated Process Skills I* (Dillashaw and Okey, 1980) was used to assess the student's facility with science process skills. The 36-item test assessed the student's ability to identify variables (12 items),, identify and state hypotheses (9 items), assess operational definitions (6 items), design investigations (3 items), and graph and interpret data (6 items).

Results

Summaries of the frequencies and means of the pretest and posttest scores for each group on the TIPS and CTSR occur in Table I and Table II, respectively. Analysis of variance (Feldman, et al., 1986) of the pretest scores indicated equivalence among the groups. An ANOVA of the posttest scores on the TIPS did not show significant gains (α= .05) among the groups, but did indicate significant gains occurring within the group and gender classifications. A significant increase in the TIPS scores for the HT group (p=.0046) and among females in the QD (p=.0346) group was indicated by a paired two-tailed t-test. Similar analyses of pretest and posttest scores on the CTSR indicated no significant difference among the groups on the pretest or the posttest (α=.05). There was a significant gender effect; females across the three groups exhibited significantly lower (p=.0231) mean scores on the CTSR posttest than the males. When the CTSR scores were categorized according to Lawson's criteria for concrete, transitional, and formal, no significant effect due to gender was observed.

Table III summarizes the frequencies of the students exhibiting conditional and biconditional logic patterns on the pretest and posttest assessments of Lawson's Seven Logic Tasks. None of the students in the HT group exhibited the conditional reasoning pattern on the pretest of Task 1. Posttest analyses using chi-square indicated a relationship only between group QD and frequency of conditional reasoning on Task 5 (p=.0059). Intragroup analyses using paired two-tailed t-tests indicated that

the pretest-to-posttest gains made by group HT were significant (p=.0218). No significant effects due to gender were observed for any one group or across the three groups.

Discussion

The results of this exploratory study indicate that variations in the form of the expansion phase of the learning cycle may be effective in enhancing science process skills and the development of logical thinking. All gains of any significance were found in the HT and QD groups. The short duration of the treatment coupled with the gains made by the students in the treatment groups suggest that students could benefit when hypothesis testing and/or experimental design are added to the curriculum over a period of several years of science instruction.

The students in the HT group made significant gains on the posttest of the TIPS and on Task 1 of Lawson's SVLT. The teacher observed that the students in the HT group also had the most negative and resistant attitudes of any students among the three groups. Although positive attitudes have been considered a correlate with achievement in science, the possibility exists that any attitude, positive or negative, results in better achievement than a neutral attitude. In fact, what the teacher perceived as negative attitudes may have been disequilibration or some type of cognitive conflict on the part of the students. As the students struggled with the responsibility of developing hypotheses, designing experiments, and analyzing the results in light of the hypotheses they were exhibiting negative attitudes. They were also making positive gains in their use of process skills and at least one aspect of logical thinking. Further research would be

necessary to examine the relationship between incidences of disequilibration and the attitudes displayed among adolescents in science classes.

The apparent effect of gender on the CTSR was neutralized by categorizing the students into the traditional Piagetian groups of concrete operational, transitional, and formal operational. This suggested that the females were performing at the low end of each category. The significant gains made by the females in the QD class on the TIPS posttest suggested that the female students may benefit from a less descriptive learning cycle format. Females tend to be more verbal than their male counterparts. The use of laboratory exercises requiring intense verbal interactions among group members and the development of a written report of those activities may lead to increased use of science process skills among females in a junior high science class.

One notable weakness in this study was the inability of the researcher to measure the effect of student-generated alternate hypotheses. The students in the HT group had much difficulty generating even a single hypothesis for each of the three investigations. That difficulty may have been due in part to the lack of context-dependent understanding the students had about simple machines. A related study (Rogers & Westbrook, 1991) indicated that these students had an understanding of the terms used in these investigations based on personal experience and context. It may have been difficult for the students to separate the concepts taught and used in the investigation from a previously held context. This explanation is supported by the researcher's attempt to have students generate hypotheses about

the factors that determine whether an object will or will not float. In that study the same students were able to generate several alternative hypotheses about the factors that explain floating and argue contradictions among those hypotheses. If the basis of student learning is experience, then it seems reasonable to suggest that the student's familiarity with a concept within the context of the content being taught would effect the quality and quantity of hypotheses the student could generate.

Another explanation for the lack of generated alternative hypotheses could be that a strict interpretation of Piaget's quality of thought model suggests that ninth grade students are not capable of generating and testing hypotheses. While these students do not generate the same quantity or quality of hypotheses as reflective adults, they can engage in activities that provide experiences related to hypothesis testing. Lawson (1990) argued that the logic of reasoning to a contradiction, necessary for generating and testing hypotheses, could be observed in an unrefined state in students in the third and fifth grade. These data support the contention to include the essence of logic in the science curriculum in junior high schools. Lawson, Lawson, and Lawson (1984) reported that internalization of certain aspects of the linguistics of argumentation were prerequisite for the development of proportional reasoning. Lawson (1987b) recommended a science curriculum designed to teach students to reason to a contradiction as a means of enhancing reflective thinking in adolescents. Learning cycle curricula could be rewritten to provide junior high and high school science students with these experiences and strategies.

Conclusion and Implications

A good model of instruction should be able to weather extremes of criticism and be pliable to positive changes that would serve to enhance its effectiveness. The learning cycle is a proven model; students like it and enroll in classes where the learning cycle is used. However, students are also adaptive creatures and rote learning can occur in any situation where students are not challenged to be involved in the learning process. Variations in the form of the expansion phase of the learning cycle can be used to further challenge students who utilize higher-order reasoning and encourage the use of those skills in the more intuitive students.

The present study indicated that enhanced use of logical schema and science process skills may be achieved by students given the opportunity to design experiments or to generate and test hypotheses. These data suggest that the use of laboratory exercises alone may not be sufficient to bring about the theoretical goals of an experientially-based curriculum. It seems naive to assume that students who are provided direct experience with materials to compensate for the inability to learn from abstract presentation of the data would be able to extract the rudiments of scientific reasoning and the related processes from laboratory investigations where explicit scripts are followed. The learning cycle curriculum examined in this study was developed under the assumption that students exposed to the exploration, invention, and expansion phases or the learning cycle have learned about the true nature of science (Renner and Marek, 1990). In fact it could be argued that these students have had experiences

and described them, but have not had the opportunity to exercise higher-order reasoning skills or engage in scientific thought. The true nature of science actually centers around the idea of generating and testing multiple hypotheses rather than carrying out descriptively designated laboratory activities. Teachers and other professionals involved in curriculum development can take advantage of opportunities to allow students to generate and test hypotheses or to at least design their own experiments. These laboratory formats may not be possible for all science content across all grade levels. The data, however, suggest that use of student-generated hypothesis testing or experimental design activities for even a short duration could be beneficial.

Several questions for future research have been generated as a result of this study: What effect do the quality and number of student-generated hypotheses have on the changes in the students' logical thinking and scientific reasoning? What effect does the classroom teacher have on the quality and quantity of hypotheses generated and the effect those activities have on changes in student reasoning and use of science process skills? What do student attitudes in classes using less descriptive laboratory activities indicate about the on-going learning processes in those students? How will classroom teachers implement curricula requiring more initiative by the students and less control by the teacher? How would a school-wide curriculum committed to teaching students across all grade levels to generate and evaluate hypotheses impact the reasoning levels and science achievement in that district?

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Table 1.

TIPS pretest and posttest means by group.

	Pretest		Posttest	
Group/Gender	$\bar{x}$	σ	$\bar{x}$	σ
CT (n=24)	17.71	6.51	19.58	7.49
F (n=13)	20.54	6.29	21.23	7.67
M (n=11)	14.36	6.87	17.64	6.58
QD (n=18)	18.90	6.16	21.83	7.94
F (n=6)	17.67	7.47	23.17	8.80
M (n=12)	19.50	5.67	21.17	7.79
HT (n=20)	19.05	6.25	23.05	0.24
F (n=13)	18.39	5.72	22.85	6.99
M (n=7)	20.29	7.46	23.43	8.26

Note. $\bar{x}$ refers to mean of sample; s refers to standard deviation of sample; CT refers to control group; QD refers to question design group; and HT refers to hypothesis testing group.

Table 2.

CTSR pretest and posttest means by group.

	Pretest		Posttest	
Group/Gender	$\bar{x}$	σ	$\bar{x}$	σ
CT (n=20)	4.85	1.95	5.15	1.98
F (n=12)	4.42	2.02	4.83	1.85
M (n=8)	5.50	1.77	5.63	2.20
QD (n=17)	4.71	1.99	4.77	1.86
F (n=7)	4.43	1.90	4.29	2.14
M (n=10)	4.90	2.13	5.10	1.66
HT (n=19)	4.21	2.07	4.53	1.74
F (n=14)	3.79	1.89	4.00	1.71
M (n=5)	5.40	2.30	6.00	0.71

Note. $\bar{x}$ refers to mean of sample; s refers to standard deviation of sample; CT refers to control group; QD refers to question design group; and HT refers to hypothesis testing group.

Table 3.

Seven Logic Tasks by group

	Pretest				Posttest			
Task	B	C	$\bar{x}$	σ	B	C	$\bar{x}$	σ
				Hypothesis Testing Group				
1	24	0	1.00	0.00	19	5	1.21	0.42
2	22	2	1.08	0.28	21	3	1.13	0.34
3	21	3	1.13	0.34	22	2	1.08	0.28
4	23	1	1.04	0.20	22	2	1.08	0.28
5	24	0	1.00	0.00	23	0	1.00	0.00
6	23	0	1.00	0.00	22	1	1.04	0.21
7	23	0	1.00	0.00	22	1	1.04	0.21
				Question Design Group				
1	16	4	1.20	0.41	12	8	1.40	0.50
2	16	4	1.2	0.41	13	7	1.35	0.49
3	19	1	1.05	0.22	16	4	1.20	0.41
4	19	1	1.05	0.22	17	3	1.15	0.37
5	19	1	1.05	0.22	15	5	1.25	0.44
6	20	0	1.00	0.00	20	0	1.00	0.00
7	20	0	1.00	0.00	20	0	1.00	0.00
				Control Group				
1	22	4	1.15	0.37	17	9	1.35	0.49
2	22	4	1.15	0.37	19	7	1.27	0.45
3	25	1	1.04	0.20	24	1	1.00	0.28
4	26	0	1.00	0.00	23	3	1.12	0.33
5	25	1	1.04	0.20	25	1	1.04	0.20
6	26	0	1.00	0.00	26	0	1.00	0.00
7	26	0	1.00	0.00	24	1	1.04	0.20

Note. B refers to biconditional reasoning. C refers to conditional reasoning; x refers to mean of sample; s refers to standard deviation of sample.